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OVERVIEW OF ROTORCRAFT AND GENERAL AVIATION PROPULSION TECHNOLOGY

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This paper presents an overview of NASA'S propulsion research that is aimed at applications for rotary winged flight and general aviation. The strategic goal of this research effort is to provide innovative technologies that will strengthen the nation's competitive stance in the world market for the civil sector, and also provide superior rotorcraft for U.S. military use.

NASA and the U.S. Army work hand-in-hand on rotorcraft propulsion research at NASA Lewis Research Center. This is made possible by a cooperative NASA-Army agreement which has situated the Army's center for basic propulsion research at Lewis.

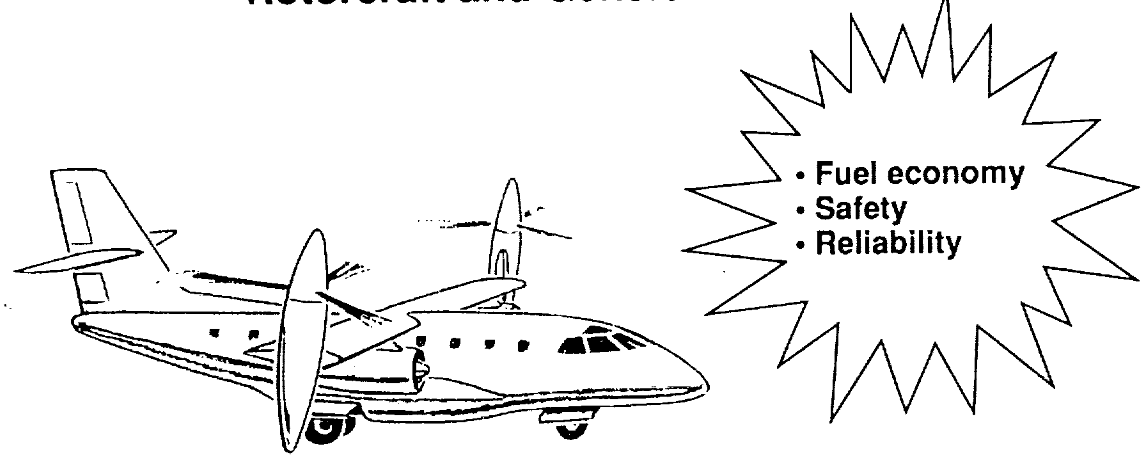
The NASA Lewis tactical plan for achieving this strategic goal is to (1) reduce fuel consumption of small engines by 30 percent through use of advanced cycles (including higher pressure and temperature operation) and with improved turbomachinery components technology and ceramic materials, (2) contribute to fuel savings through weight savings and to reliability by developing advanced technology for transmissions, (3) contribute to aircraft safety by providing advanced anti-icing and deicing technology,[1] and (4) achieve high-speed capability through advanced propulsion systems.

In this session of the conference, the work efforts that are directed at meeting these challenges are reviewed. In this paper, high-speed propulsion studies aimed at enabling 450-kn rotorcraft are reviewed.

Subsequent papers review the following focused projects: (1) rotary engine technology that will achieve multifuel capability, a power density of 5 hp/in.^{3} engine displacement, and a specific fuel consumption of 0.35 lb/hr/hp, and (2) advanced rotorcraft transmissions that reduce weight by 25 percent, reduce gear noise by 10 dB, and increase mean time between removal to 5000 hr. Also reviewed is the base research and technology effort in turbomachinery for small engines. This includes research directed at compressor technology achieving 24-to-1 pressure ratios and 83 percent polytropic efficiency, combustor technology achieving 3000 °F capability and more uniform combustor exit temperature distributions as described by a 0.1 pattern factor, and turbine technology achieving 88- to 90-percent adiabatic efficiency and cycle temperatures of 2600 °F.

[1]The Aircraft icing technology is presented in the session on Multidiscipline Research.

Rotorcraft and General Aviation



Systems study
- **High-speed propulsion systems**

Focused projects
- **Rotary engine**
- **Advanced transmission - ART**

Base R&T
- **Compressors**
- **Combustors**
- **Turbines**
- **Transmissions**

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This paper presents an overview of NASA'S propulsion research that is aimed at applications to rotary winged flight and general aviation. The tactical objectives of the program are to (1) reduce fuel consumption of small engines by 30 percent, (2) increase fuel savings and reliability by advanced technology for transmissions, and (3) improve aircraft safety by providing advanced anti-icing and deicing technology.[2]

In this session of the conference, the work efforts shown in this figure are reviewed. To meet the goals of fuel economy, safety, and reliability, there is continuing base research and technology in small engine turbomachinery. These goals will be achieved through advanced engine cycles with higher pressure and temperature operation enabled by advanced component technology, with applications directed at compressors, combustors, and turbines. There is continuing basic research on transmission technology for lighter, quieter, and more reliable gearboxes. These base research and technology efforts are presented in more detail in the following presentations, and subsequent papers review the following efforts on focused projects: (1) rotary engine technology that will achieve multifuel capability, a power density of 5 hp/in.^{3} engine displacement, and a specific fuel consumption of 0.35 lb/hr/hp, and (2) advanced rotorcraft transmissions that reduce weight by 25 percent, reduce gear noise by 10 dB, and increase mean time between removal to 5000 hr.

The remainder of this presentation reviews the systems study on high-speed propulsion systems for 450-kn rotorcraft.

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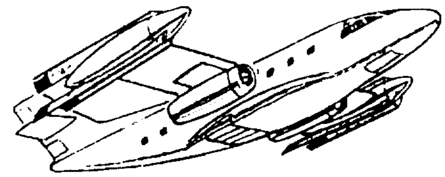
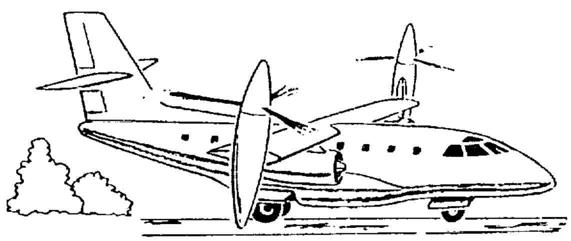
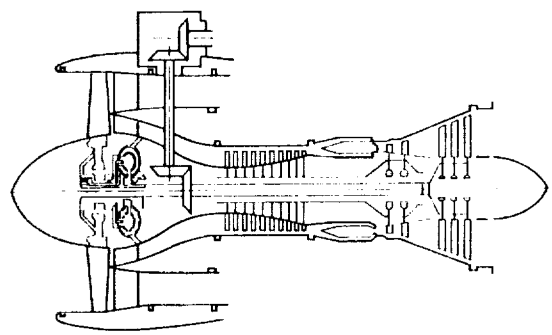
[2]Aircraft icing technology is presented in the session on Multidiscipline Research.



High-Speed Rotorcraft Propulsion Studies





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High-speed rotorcraft are those capable of cruise speeds from double those of helicopters up to Mach 0.8. The configurations of such aircraft differ greatly from those of helicopters, and their propulsion requirements, for the most part, are extremely demanding and require novel engine approaches. Studies of these rotorcraft were begun in 1988 and are being completed at the present time.

V-22 Osprey

- **Helicopter in vertical mode**
- **320-kn turboprop in cruise**

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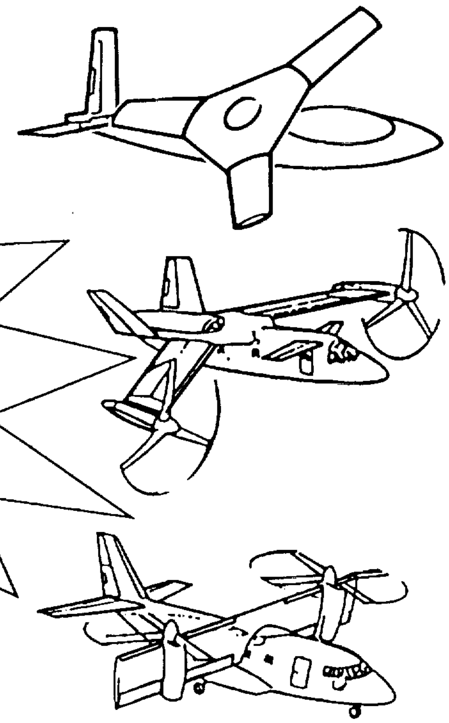
The first mission-capable, high-speed rotorcraft is the V-22 Osprey, a military vehicle capable of a 320-kn cruise speed. The Osprey takes off and lands like a helicopter, has hover efficiency like a helicopter, and can reposition its rotor blades to fly like a turboprop. The Osprey's first flight was on March 20, 1989.

We believe that a similar civilian aircraft could be used to help alleviate the problem of airport congestion without demanding the construction of additional runways. Studies on the application of this type of vehicle have been in progress since 1984 and have considered the global issues of transportation strategy and market strategy, as well as technology barriers. These studies concluded that a good market exists, that there is indeed a place for such a vehicle in the transportation industry, and that civil-specific technology must be developed rather than adapting the military technology. A major issue that has to be addressed is the integration of the civil tilt rotor into the infrastructure of the existing global transportations systems.

These studies are projecting that it is feasible to have a civil tilt rotor transportation system in place within 10 years.

High-Speed Rotorcraft Goals

- 450-kn speed
- Efficient hover
- Low noise
- Affordable
- Flexible
- Maneuverable
- Agile
- Survivable



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If rotorcraft could increase their speed to 450 kn, they could takeoff and land without runways and could combine efficient hover with the cruise speeds (and range) of current turbofan transports. Thus, the civilian version in the next century would be able to operate, in some instances, not as a feeder aircraft, but rather as the primary mode of transportation. The high speed could also be used advantageously in some military operations. The assumed end-user requirements would be for military attack, military transport, and civil transport versions of a high-speed rotorcraft.

In light of this opportunity, the NASA Ames Research Center has sponsored and directed high-speed rotorcraft studies, beginning in 1988. Their goals, which are listed in this figure, cover both civilian and military requirements.

The Government has encouraged its contractors to consider a great diversity of aircraft concepts in order to explore the maximum possible gains in capability.

High-Speed Rotorcraft Studies

Objectives

- **Identify and evaluate concepts**
- **Identify critical technology**
- **Define development plans**

Approach

- **Ames (airframe), Lewis (propulsion)**

Contractors

- **Bell, Boeing, McDonnell-Douglas, Sikorsky**
- **Allison, General Electric**

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The objectives of the high-speed rotorcraft studies were to identify attractive high-speed rotorcraft concepts (for both the airframe and propulsion system) and evaluate them against the mission requirements for military attack, military transport, and civil transport. The studies also were to identify the critical technologies that were required for success and that needed further development. They were to lay out development plans that would bring the new vehicles into operation by the turn of the century.

The airframe studies have been funded and directed by Ames Research Center. Coordinated with these studies, but separately funded and directed by Lewis, are the propulsion studies.

The helicopter airframe companies involved are Bell, Boeing, McDonnell-Douglas, and Sikorsky. The propulsion companies are Allison and General Electric.

Space limitations and the propulsion theme of the conference do not permit a complete review of the airframe-related findings of these studies. Briefly stated, weight reduction technology will be a big factor in achieving the goals, and we expect that it will be accomplished through innovative structural design techniques and advanced lightweight materials. The propulsion aspects of the studies are reviewed next.

Propulsion Study Process

(1) Identify concepts

(2) Match to airframe and mission

(3) Scale performance

(4) Identify key technologies

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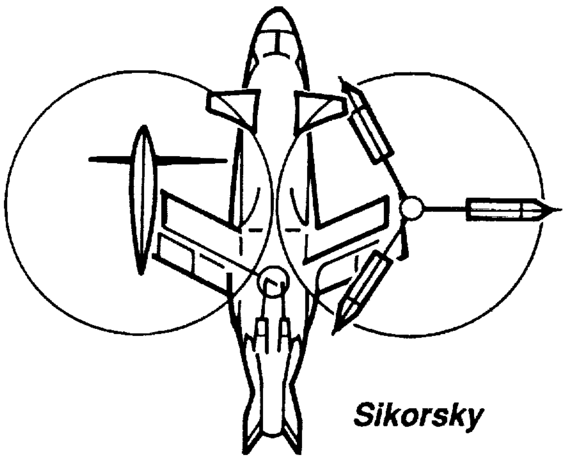
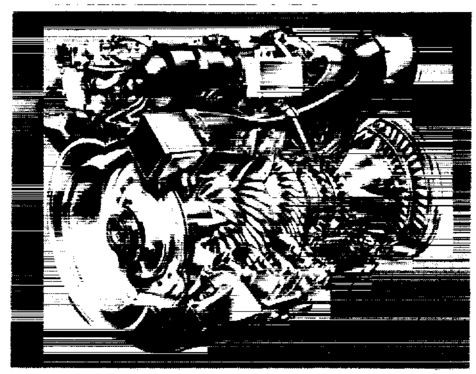
There were four steps in the propulsion study efforts: (1) identify the engine concepts that are suitable for high-speed rotorcraft; (2) from those identified, select the engine concepts best suited for each rotorcraft and mission combination that was identified in the Ames study; (3) for the selected engine concepts, estimate the performance, weight, and other characteristics, and scale the engines over a useful range; and finally, (4) identify the key technologies that need to be developed to have a viable propulsion system for high-speed rotorcraft.

The results of the airframe studies have been examined, and necessary modifications in engine concepts and identification of required technologies have been made. This process has been repeated in an iterative manner in order to determine the most appropriate direction for future work.

Proposed Rotorcraft and Candidate Engines

Variable–Diameter Tilt Rotor





Conventional Turboshaft Engine

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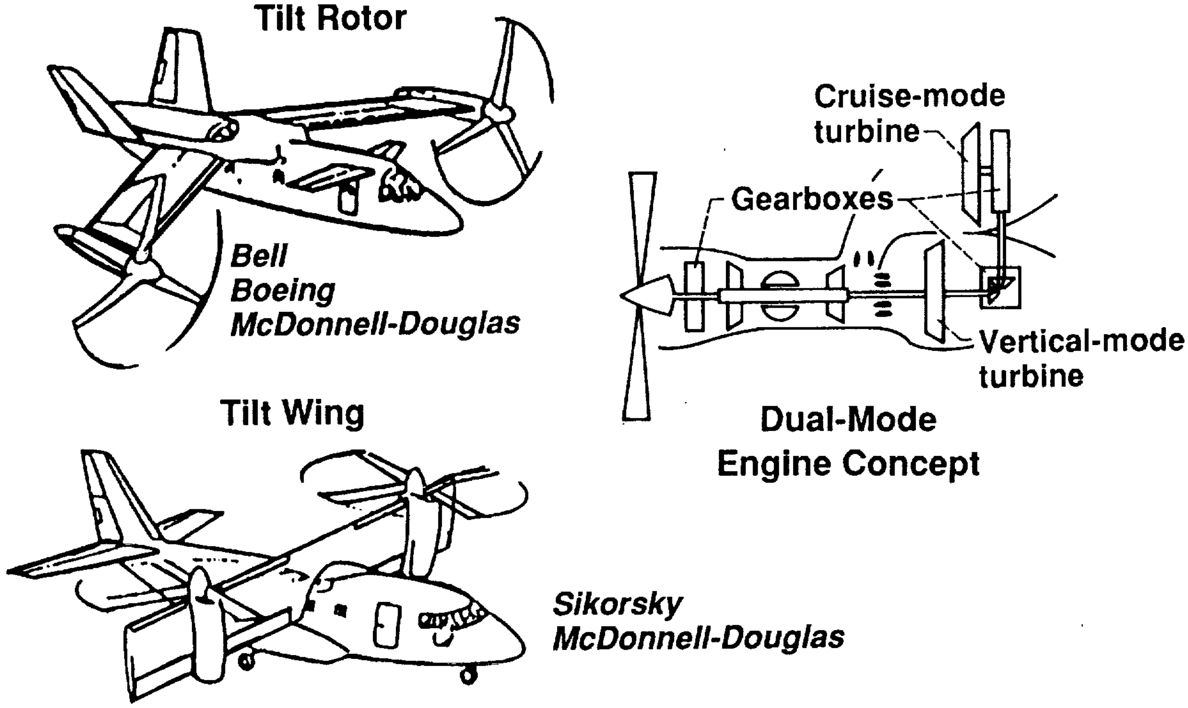
The high-speed rotorcraft airframe studies have defined several interesting vehicle concepts - each dependent on the mission requirements (civil or military). In general, 450 kn was found to be the maximum practical speed - beyond that, the weight penalties began to increase at an ever-increasing rate.

In the next few figures, the aircraft chosen in the high-speed rotorcraft studies for final evaluation are shown along with the specific engine requirements for each.

Shown here is a high-speed tilt rotor aircraft capable of 450 kn. It has highly swept wings and canard control surfaces. To prevent the helical tip speed of the rotor from approaching Mach 1 during cruise, the variable-diameter rotor can be reduced in size for high-speed cruise. The required engine would be a rather standard turboshaft engine, and the only new technology required would be the application of IHPTET GEN 6 (turbine engine) technology to reduce fuel use and weight.

This configuration is a Sikorsky candidate, intended for the military transport and the military scout-attack missions at gross weights of approximately 40 000 and 25 000 lb, respectively.

Proposed Rotorcraft and Candidate Engines



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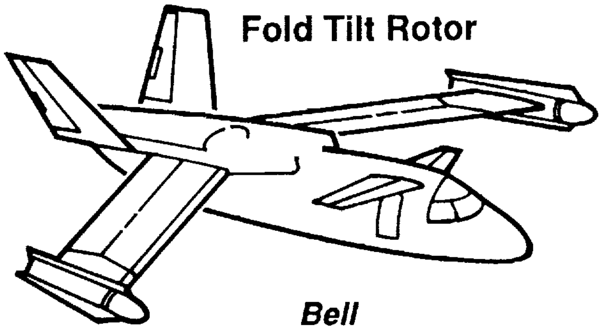
Bell, Boeing, and McDonnell-Douglas investigated similar high-speed tilt rotors with constant-diameter rotors. McDonnell-Douglas and Sikorsky suggested tilt wing aircraft, also with constant-diameter rotors.

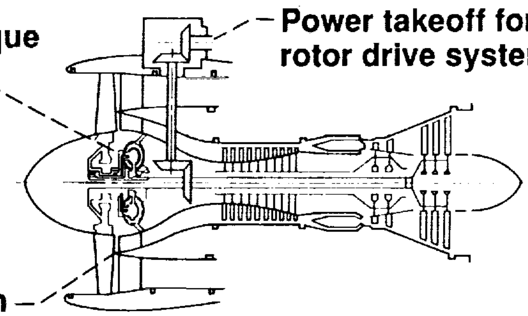
Here, propulsion systems capable of operating efficiently at constant power, but with lower rotational shaft speeds at cruise are required to keep the rotor helical tip speed subsonic. A conventional turboshaft engine with a two-speed transmission would be feasible.

However, the new dual-mode engine concept would not need a two-speed transmission. The configuration illustrated in this figure is merely an example. In the vertical mode, the vanes direct all the flow to the low-speed, vertical-mode turbine. During high-speed cruise, the vanes direct all the flow to the cruise-mode turbine, which would rotate at design speed for maximum efficiency. The gearboxes reduce the speed to drive the rotor blades at their most efficient speed.

The actual definitions of efficient dual-mode concepts are still being developed. Since such engines do not exist now, the technological work required is expected to be significant.

Proposed Rotorcraft and Candidate Engines





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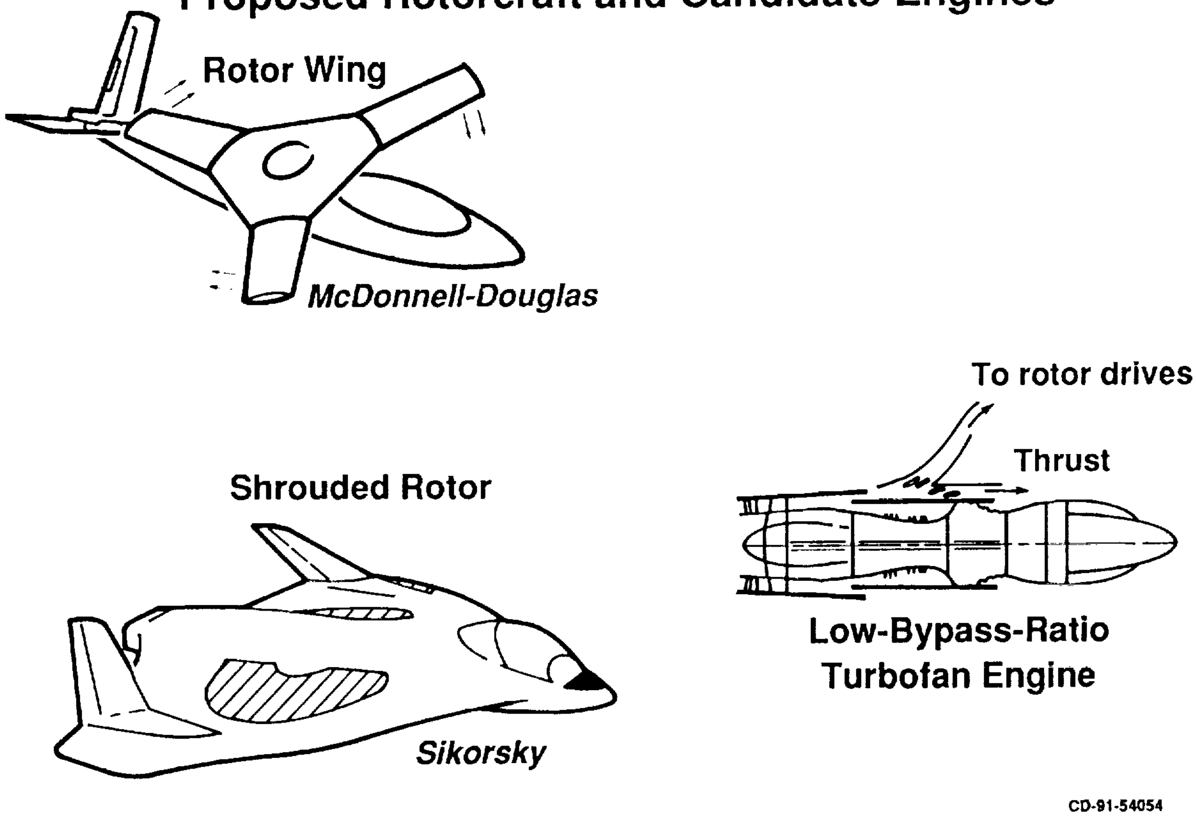
Both Bell and Boeing have proposed a fold tilt rotor. Here the rotors are stopped and folded during cruise and the turboshaft engines required for takeoff, landing, and hover become turbofans. This configuration is capable of speeds higher than 450 kn.

The propulsion system that changes from turboshaft to turbofan is called a convertible engine. The example shown here has a fixed-pitch fan that would be decoupled during turboshaft operation. For cruise, a torque converter would be used to bring the fan up to speed. Then, the fan would be locked to the shaft and the torque converter would be drained to prevent power losses and excessive heat generation. A clutch would decouple the rotor drive system.

There are other convertible engine concepts which will be shown later.

Proposed Rotorcraft and Candidate Engines



The McDonnell-Douglas rotor wing concept is propelled by a tip-blown rotor at low-speed and hover conditions. For high-speed cruise, the rotor is stopped to become a wing. This configuration is envisioned as capable of speeds higher than 450 kn, and since there is no need for a transmission, the weight penalty is considerably reduced.

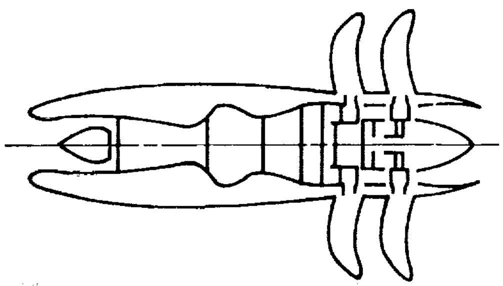
Sikorsky's shrouded rotor concept uses a separate turbine to operate the rotor. Essentially it is a fan-in-wing aircraft.

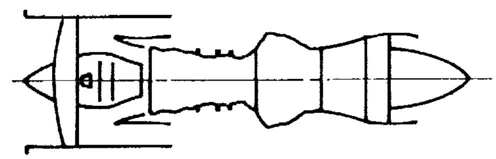
The minimum weight propulsion system that satisfies the propulsion needs for these aircraft is a low-bypass-ratio turbofan. Such an engine would have high fuel consumption in cruise. However, little, if any, rotorcraft-specific technology appears necessary.

It is possible that some type of dual-mode system with low bypass during rotor operation and high bypass during cruise would be beneficial. Only very detailed vehicle and mission-specific tradeoff studies would determine that.

Preferred Convertible Engines

General Electric *Allison*





Geared Pusher Propfan (UDF)
- **Variable pitch**
- **8 blades in 2 rows**

Clutched Fan
- **With torque converter**
- **1.6 fan pressure ratio**
- **6.0 bypass ratio**

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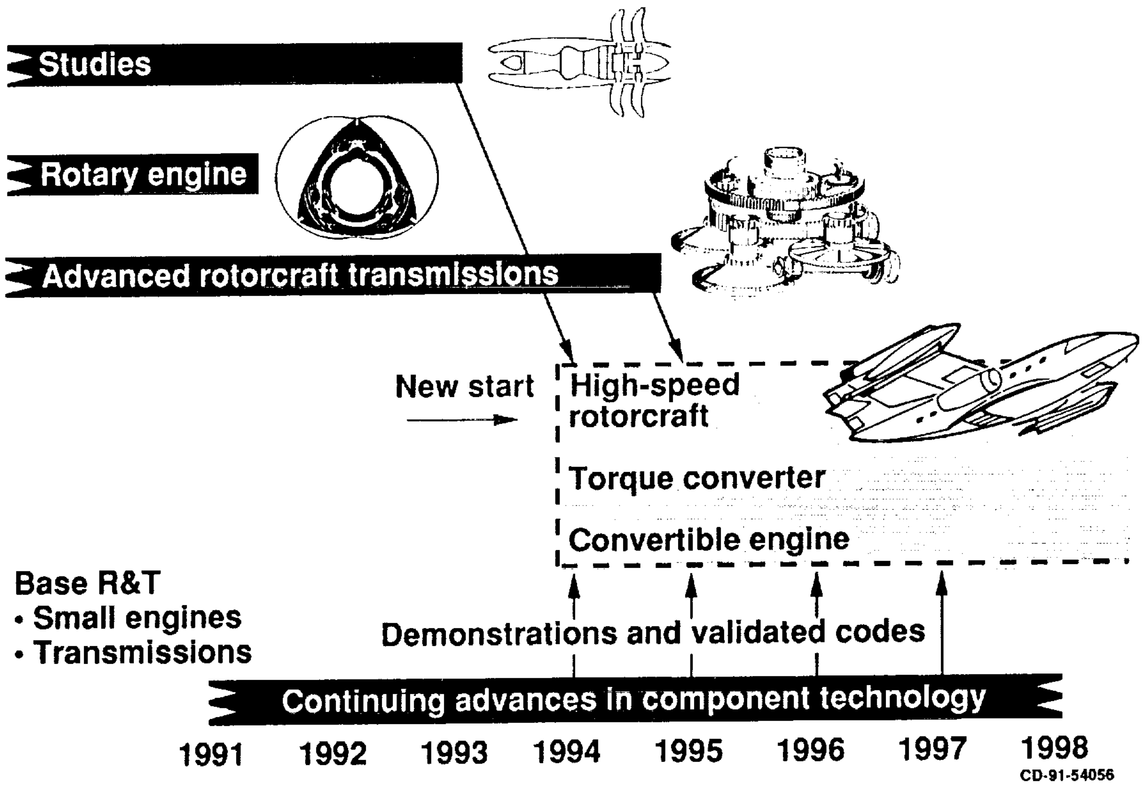
In these propulsion studies, convertible engines have been the first concepts to be fully defined. A number of concepts for convertible engines are considered viable candidates. All of the concepts provide for conversion between turboshaft or turbofan operation.

General Electric suggested a geared unducted fan (UDF) as its first choice, a clutched fan engine using the torque converter as its second choice, and a variable inlet guide vane engine as its third choice.

Allison chose a clutched fan engine using the torque converter concept as its first choice, a turbofan with a variable pitch fan as its second choice, and a variable inlet guide vane engine as its third choice.

The studies have identified additional technology needs. The unducted fan engine requires a gearbox in the hot section - something that has not been done before. And the clutched fan engine requires a torque converter with a power and torque capability 10 times that of current torque converters. Use of variable inlet guide vanes to block fan flow during shaft operation would produce very high power losses during shaft operation unless the technology improves. Use of variable-pitch fans in this application could have weight and aerodynamic penalties unless new technology is applied. Of course all engines will benefit from the application of IHPTET GEN 6 technology.

Rotorcraft and General Aviation Propulsion Program



This figure shows the current activity and the proposed future plan for rotorcraft and general aviation.

The studies that are nearing completion have brought forward some very exciting concepts for airframes and propulsion systems. The rotary engine project has advanced the technology for future production of efficient, high-power density, multifuel engines for commuter aviation. The Advanced Rotorcraft Transmission (ART) project is providing demonstrated, viable transmissions for the Army's next generation of transport and attack-scout rotorcraft. The base research and technology effort in components for small engines and transmissions will continue to infuse into propulsion systems the latest technology for advanced components and validated computer codes, making use of the unique experimental and computational facilities that exist at NASA Lewis.

Looking ahead, a new technology initiative is being prepared for high-speed rotorcraft propulsion - including torque converters, convertible engines, and the related propulsion technologies. We envision that such work, beginning by fiscal year 1994, will be part of a larger, three-NASA-center, high-speed rotorcraft program, to be performed by the Ames, Langley, and Lewis Research Centers, with Lewis concentrating on the propulsion aspects. We project that such a program could enable a 450-kn rotorcraft in the early part of the 21st century.

SUMMARY

This paper has reviewed NASA's propulsion research program for rotorcraft and general aviation, whose expressed strategic goal is to provide the innovative technologies to maintain U.S. rotorcraft and general aviation leadership in the world market and in military capability.

The plan for achieving this goal is (1) to reduce fuel consumption of small engines by 30 percent through the use of advanced cycles, including higher pressure and temperature operation, and the use of improved turbomachinery components technology and ceramic materials; (2) to increase fuel savings and reliability by advanced technology for transmissions; (3) to improve aircraft safety by providing advanced anti-icing and deicing technology; and (4) to achieve high-speed rotorcraft capability through advanced propulsion systems.

NASA's high-speed propulsion studies are aimed at enabling 450-kn rotorcraft. These studies have concluded that no single airframe configuration is best for the three missions of civilian transport, military transport, or military attack. Demanding propulsion technology is required for the configurations that have been identified. If a new technology initiative can begin as early as 1994 for high-speed rotorcraft, including the related propulsion technology, such work could enable a 450-kn rotorcraft early in the next century. The new initiative would provide for work on convertible engines, dual-mode engines, torque converters, gearboxes for hot operation, two-speed transmissions, optimized variable inlet guide vanes and variable pitch fans, and variable-diameter rotors.

The remaining papers in this session of the conference review the current progress and future direction of work in turbomachinery technology for small turbine engines (including compressors, combustors, and turbines), rotary engines, and transmissions. The papers highlight the strong cooperation on propulsion research between NASA Lewis and the U.S. Army, which has existed for two decades.